Recent CFD Research in the SimLab FSE

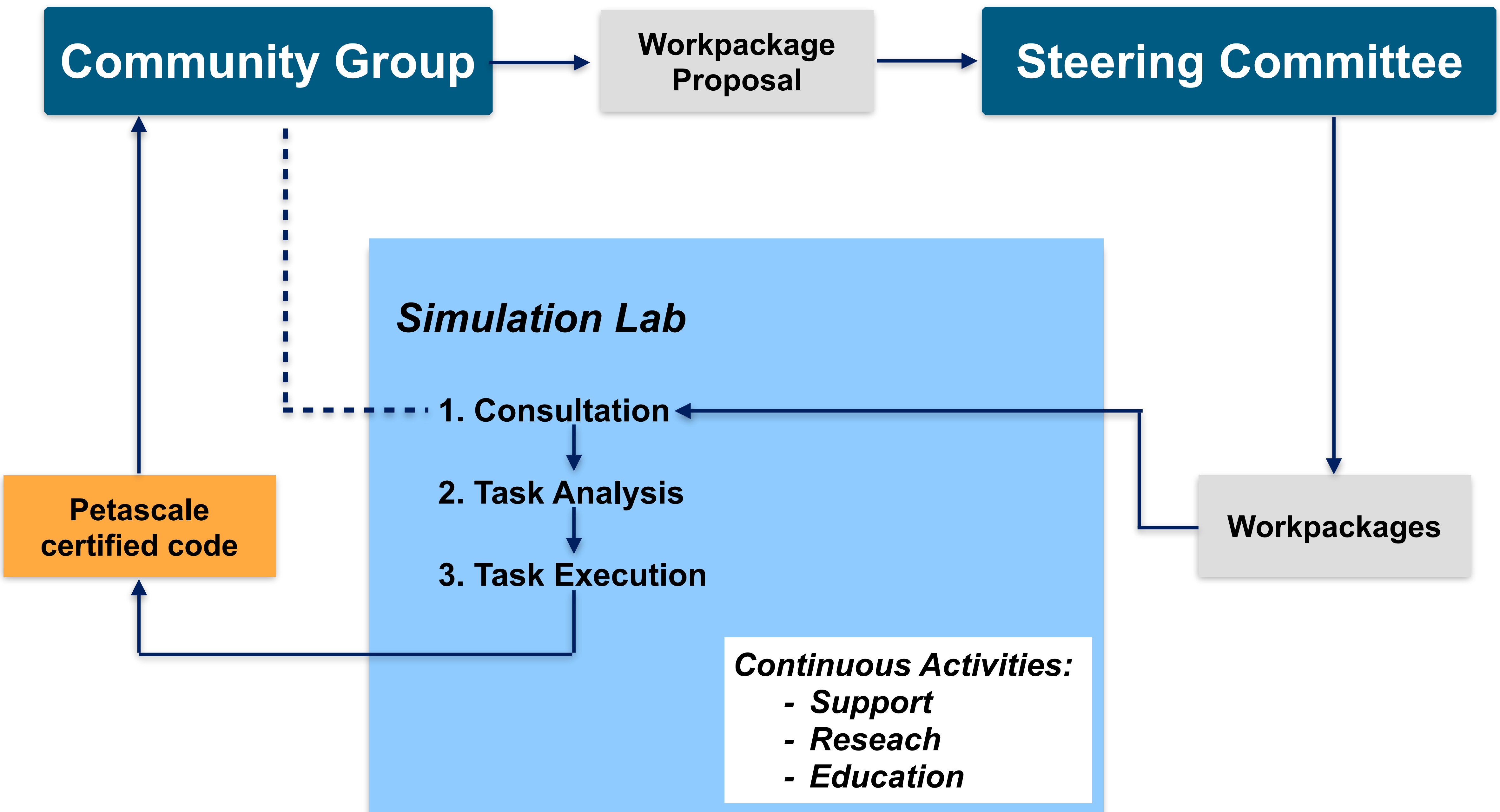
JLESC Workshop

30. June 2015 | Andreas Lintermann
SimLab “Highly Scalable Fluids & Solids Engineering”, JSC, FZ Jülich / JARA-HPC, RWTH Aachen

Overview

- SimLab concept - What is a SimLab?
- SimLab research projects in the fields of
  - Biofluidmechanics
  - Aeroacoustics
- Challenges for future research projects
- Summary

What is a Simulation Laboratory?



SimLab Structure

SimLab "Highly Scalable Fluids & Solids Engineering"

Members

Metin Cakircali
MSc.

Manuel Kosel
Dipl.-Ing.

Michael Schlottke
Dipl.-Ing., MSc.

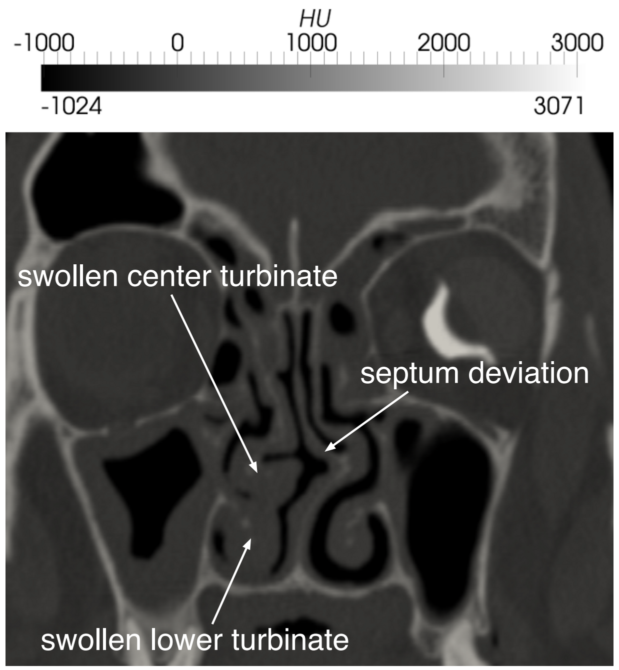
Andreas Lintermann
Dr.-Ing. Dipl.-Inform.

Biofluidmechanics:

Flow in the Human Nasal Cavity

Motivation:

- **functionality of the nasal cavity**
  - olfaction, degustation, tempering, and moisturization
- **understanding pathologies**
  - strenuous respiration (common cold, allergies)
  - inflammations and lung diseases
  - loss of the sense of taste and smell

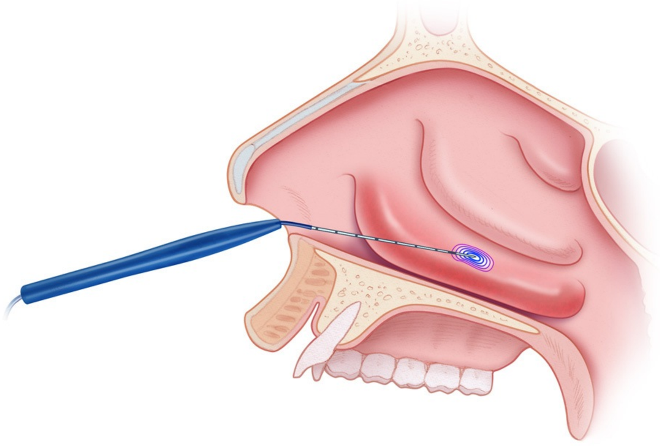


Computer Tomography image of the human head

Nose surgeries are the most common surgeries in ENT but sometimes have a low success rate

Approach:

- **use LBM to simulate the flow**
- **analyze streamlines, pressure loss, wall-shear stress, and heat release**



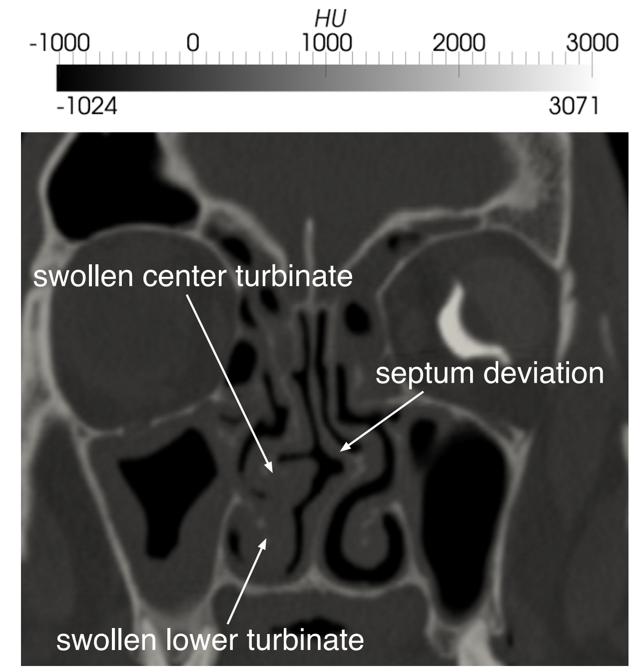
turbinate dissection by ablation

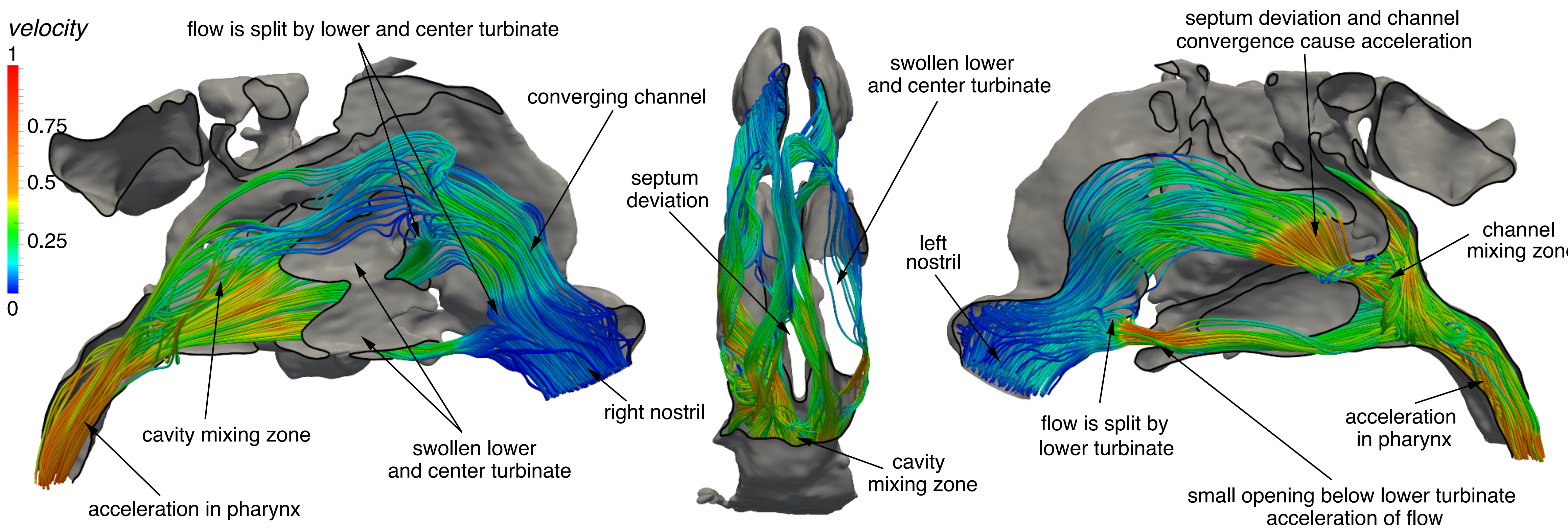
Biofluidmechanics:

Flow in the Human Nasal Cavity

The analysis of streamlines helps

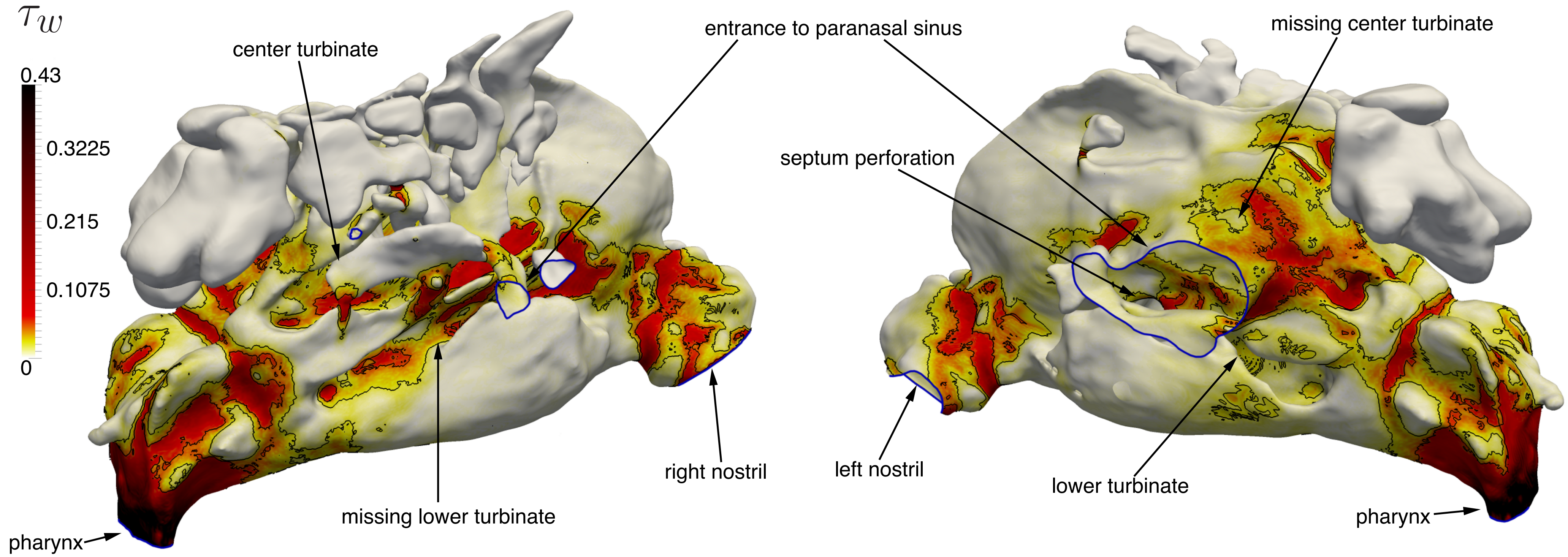
- **to identify the mass-flux distribution**
- **to understand olfactory impairment**
- **to identify converging channels**
- **to find recirculation zones**

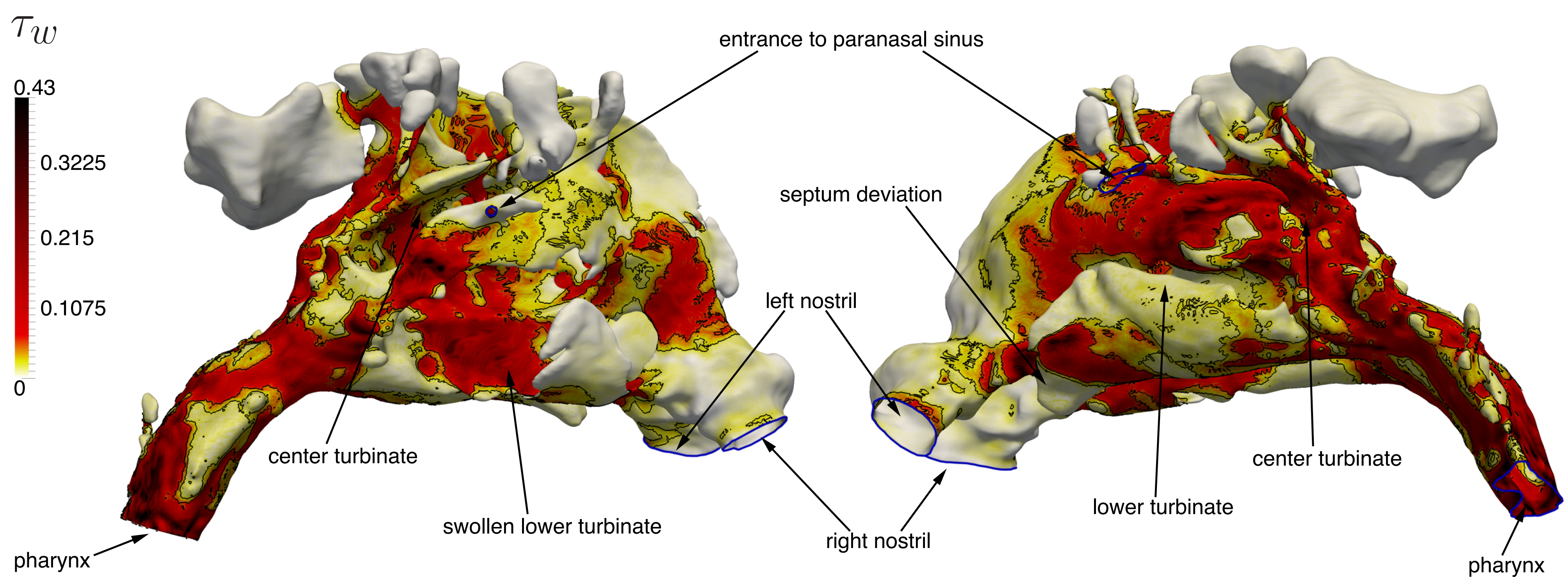




Biofluidmechanics:

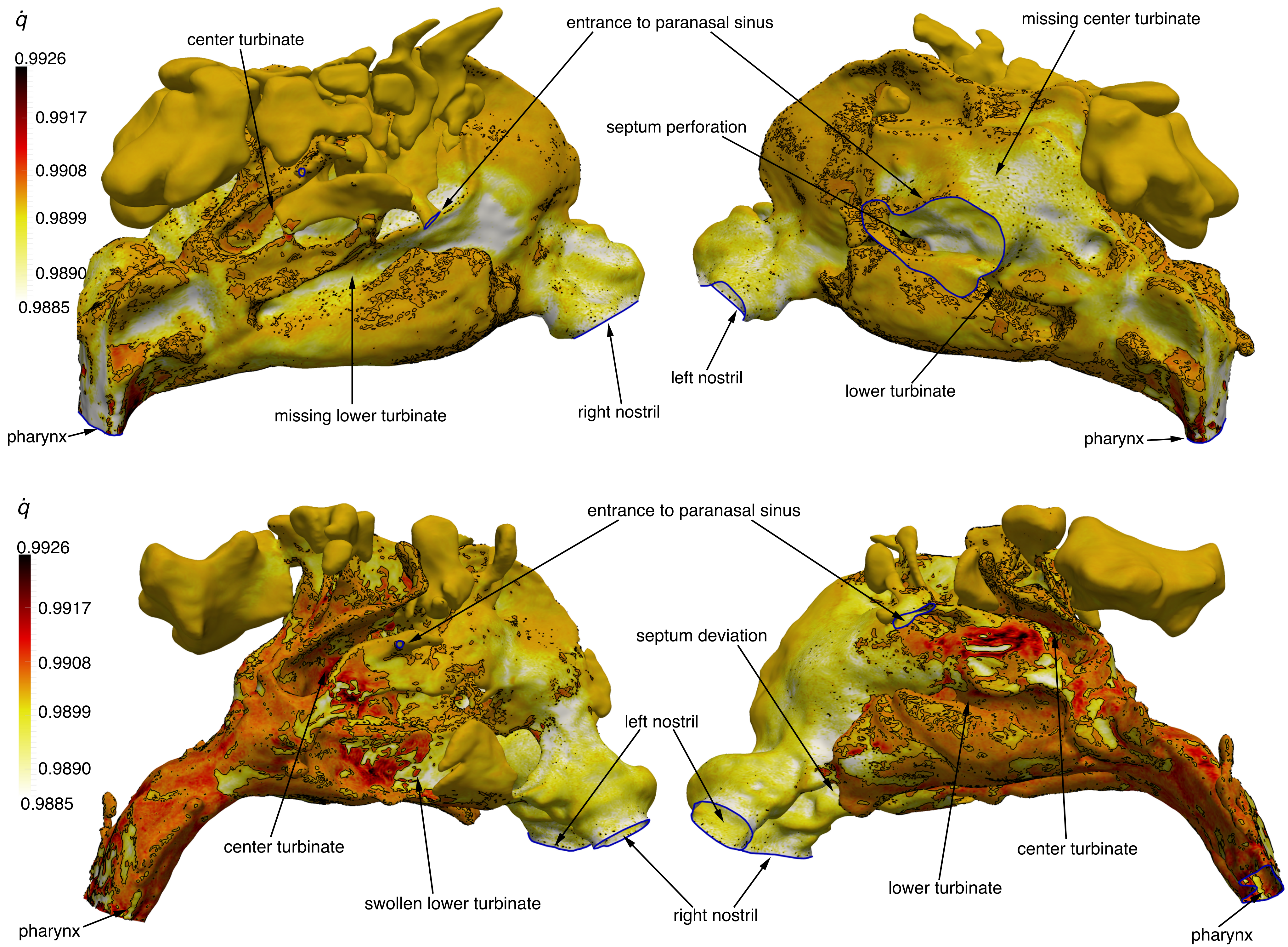
Flow in the Human Nasal Cavity (wall-shear stress)





Biofluidmechanics:

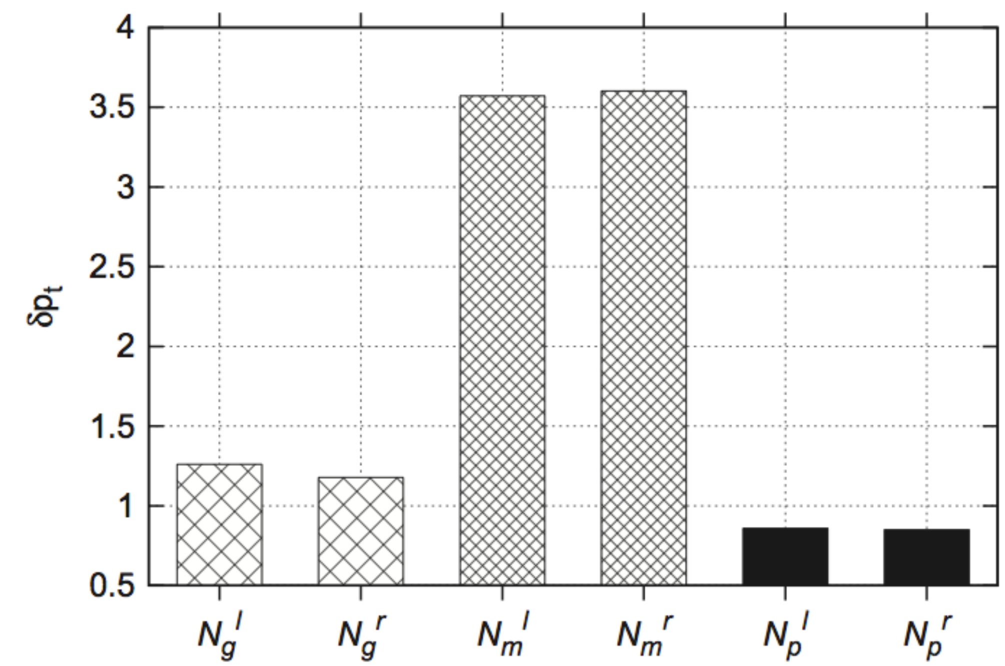
Flow in the Human Nasal Cavity (heat release)

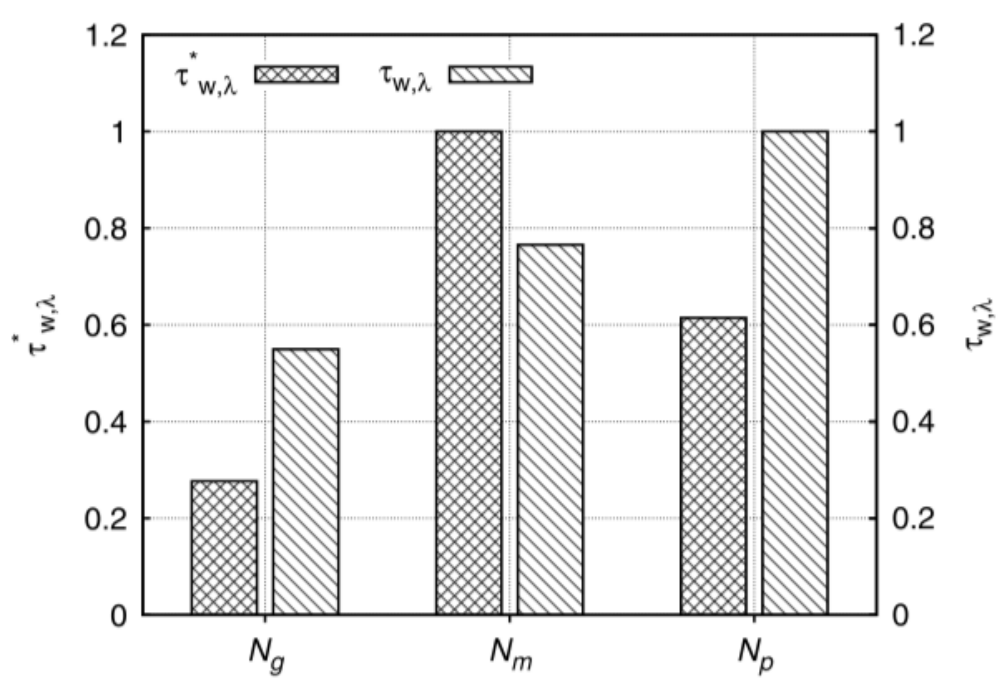


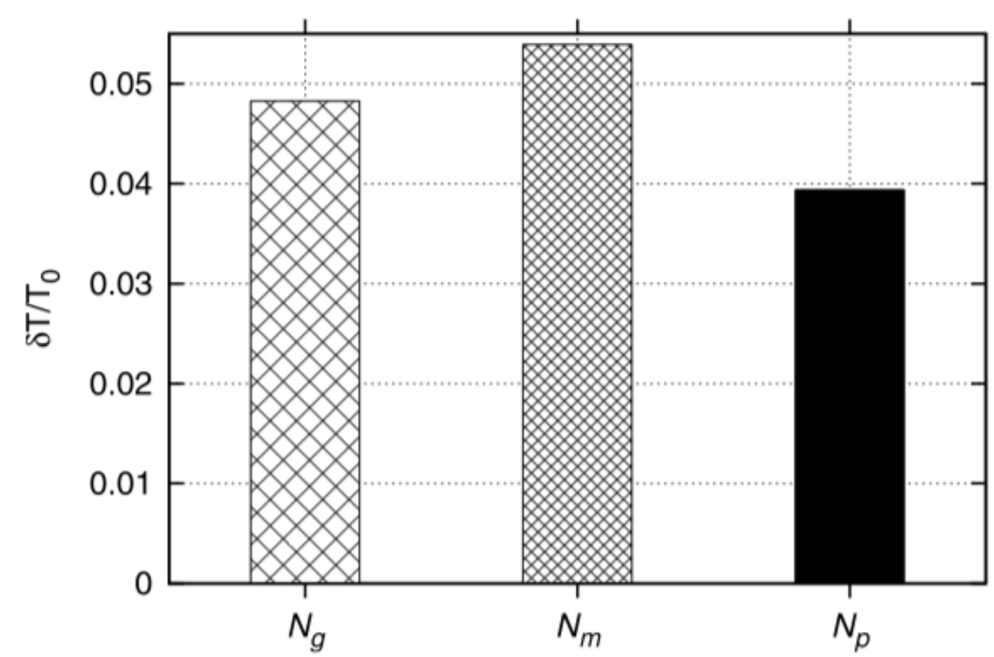
Flow in the Human Nasal Cavity

The nasal cavity efficiency is determined by the

- **total pressure loss**
- **heating capability**
- **wall-shear stress distribution**







Biofluidmechanics:

(Particle) Flow in the Human Lung

Motivation:

smog in Harbin, China

fine dust particles

Fine dust particles and Diesel aerosols **can cause lung cancer**

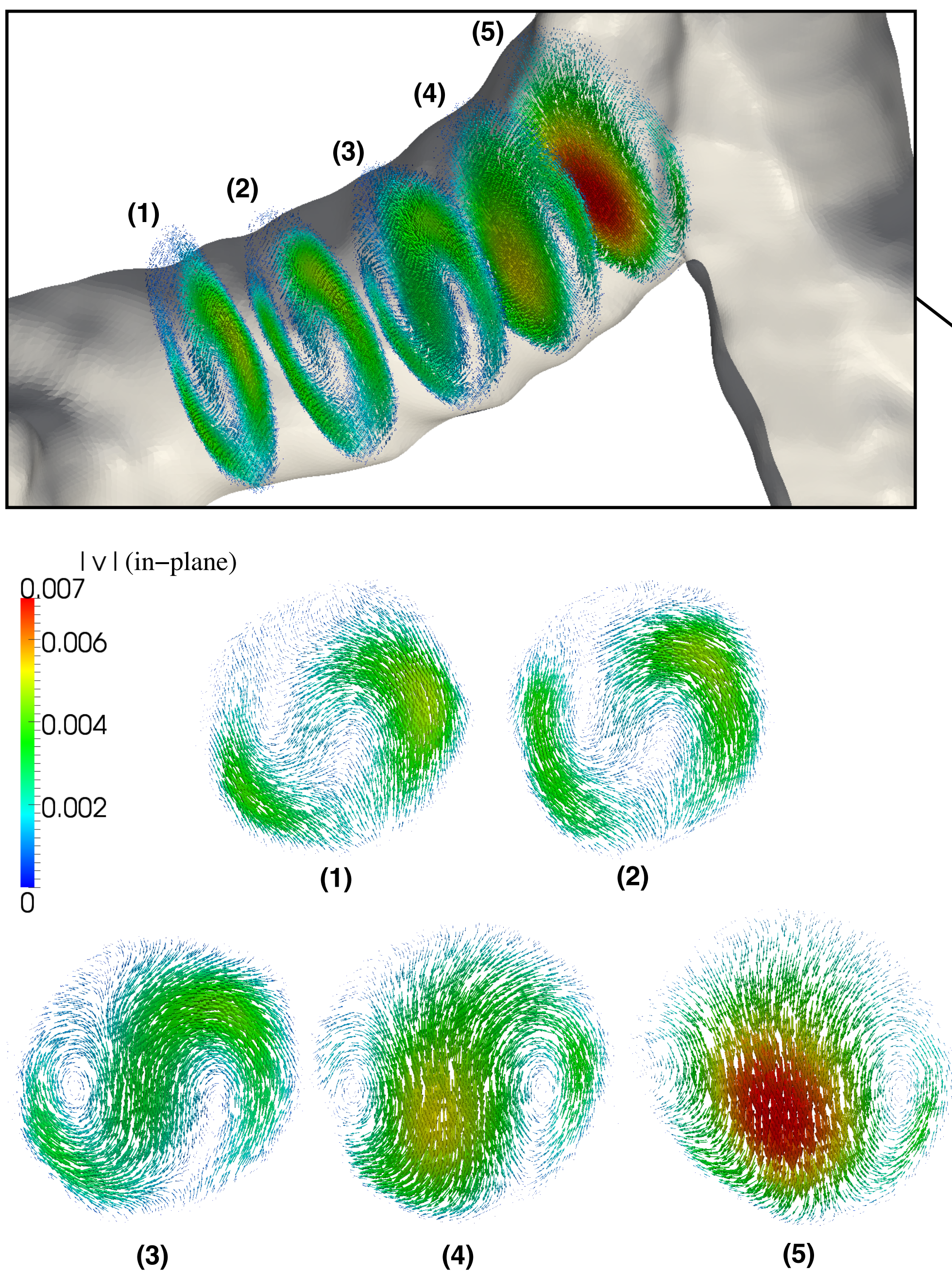
- **how are particles transported?**
- **where do they deposit?**

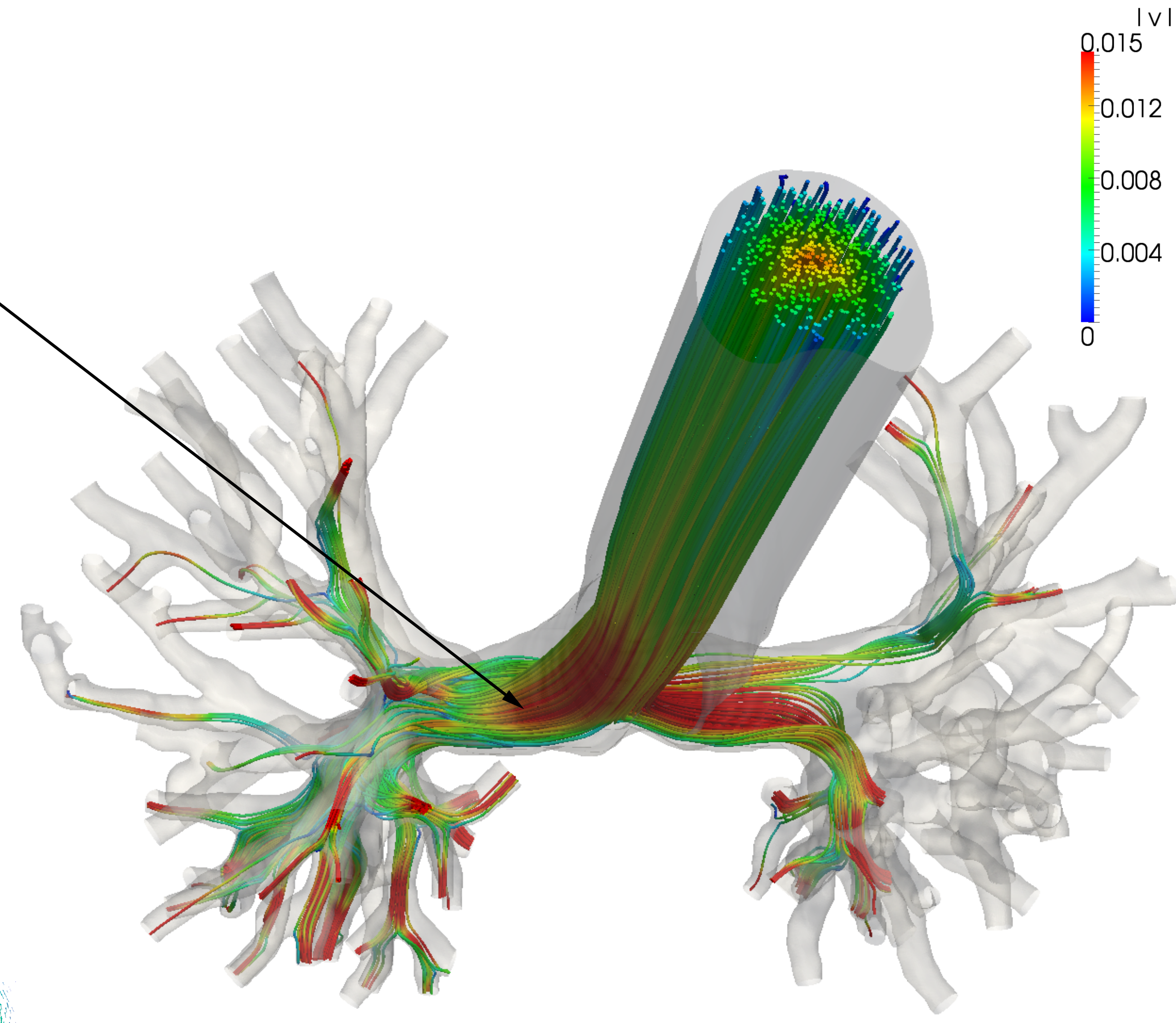
Approach:

- **use LBM to simulate the flow**
- **couple a Lagrangian particle solver to the LBM**

Biofluidmechanics:

(Particle) Flow in the Human Lung

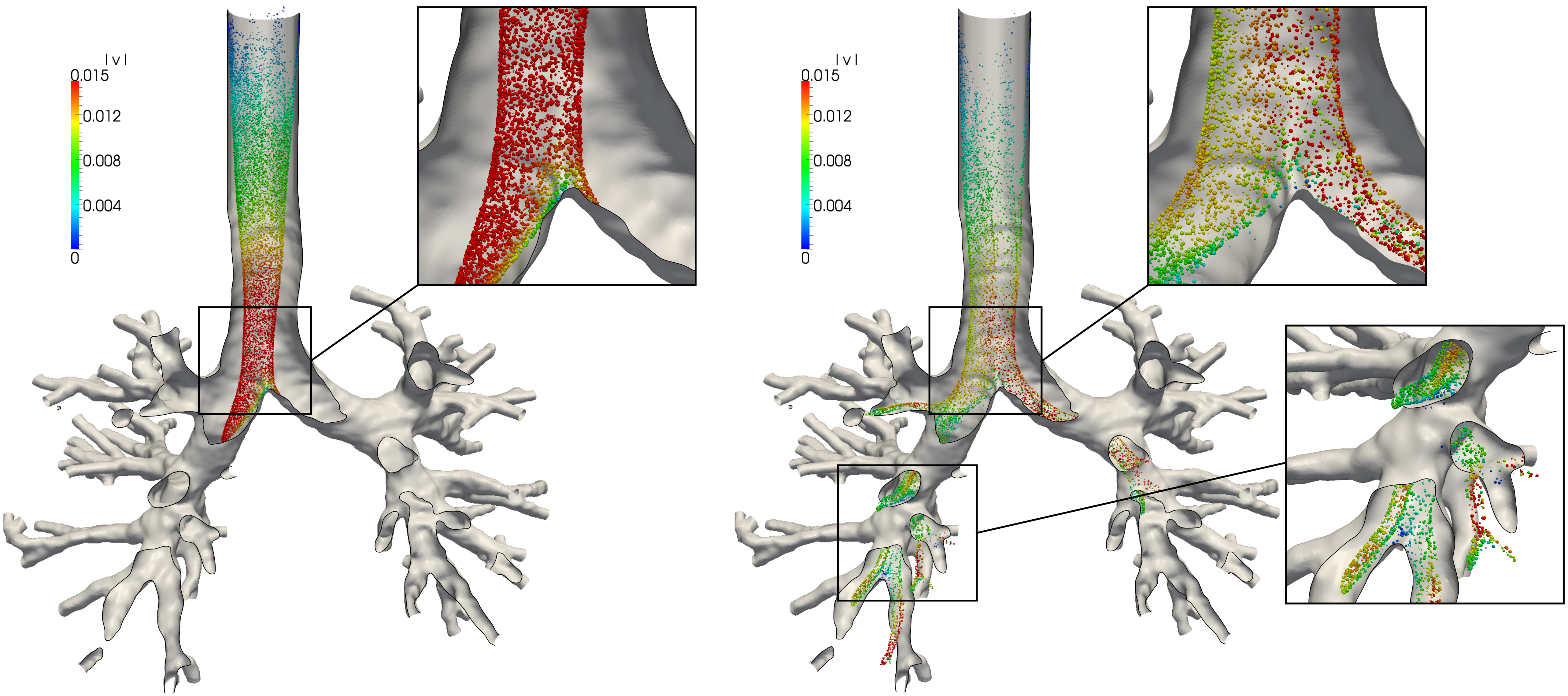




Reynolds number: $Re = \frac{uD}{\nu} = 1250$

Biofluidmechanics:

(Particle) Flow in the Human Lung



diameter: $\sigma \in [2.5\mu m, 10\mu m]$

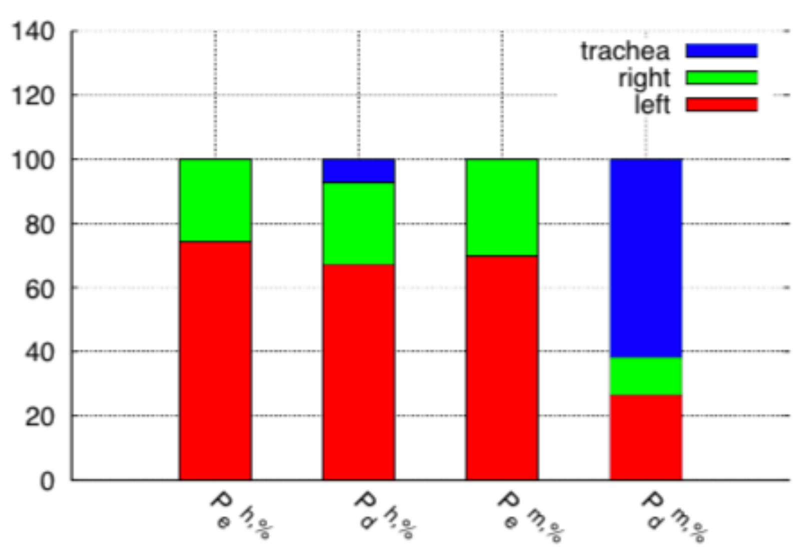
density ratio: $\frac{\rho_p}{\rho_a} \in [800, 1300]$

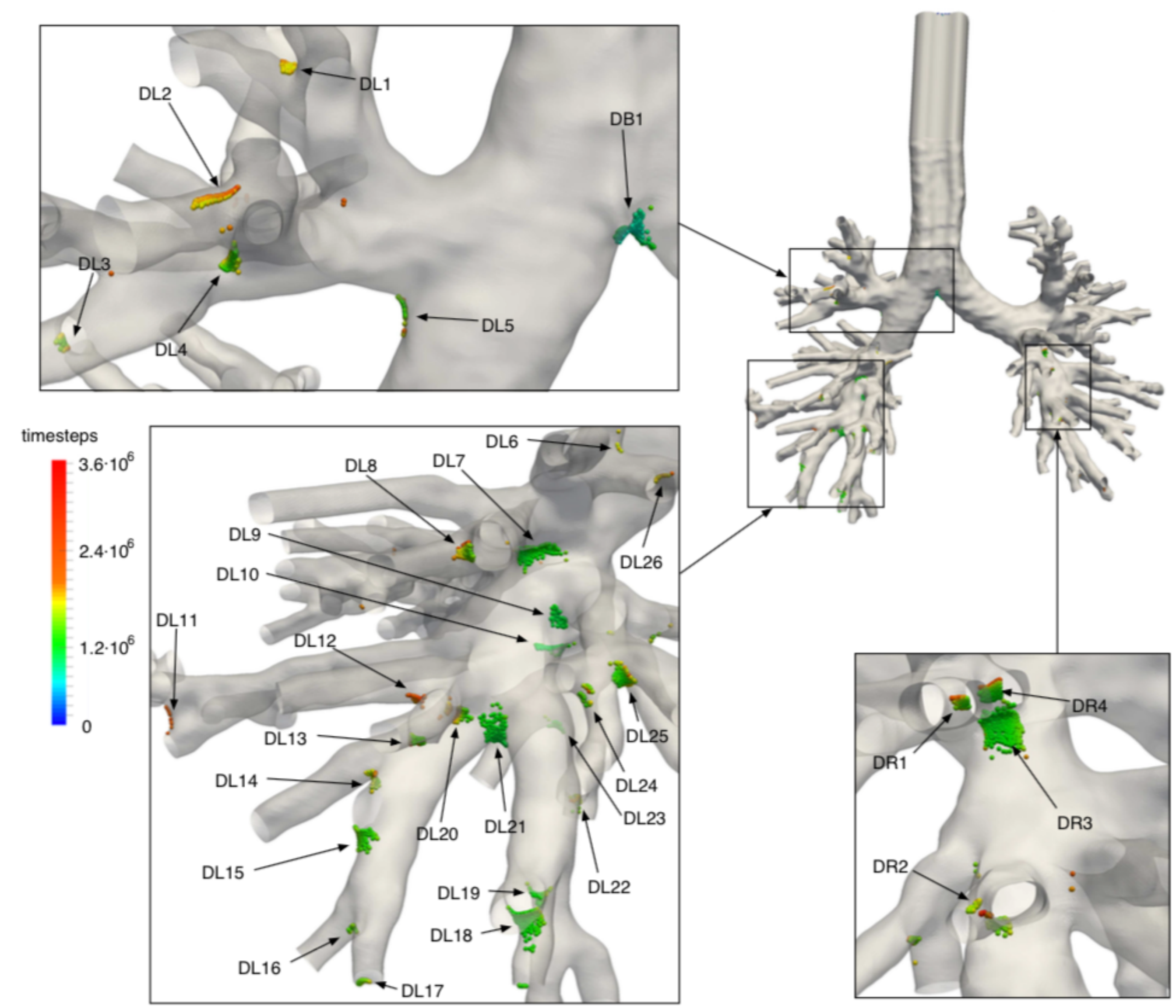
no. particles: 15×10^3

Biofluidmechanics:

(Particle) Flow in the Human Lung

	P_e	$P_e^{\%}$	P_d	$P_d^{\%}$
S^h	10211	68.07	4789	31.93
S^m	14897	99.31	103	0.69





diameter:

$\sigma = 100\mu m$

density ratio:

$\frac{\rho_p}{\rho_a} = 1300$

no. particles:

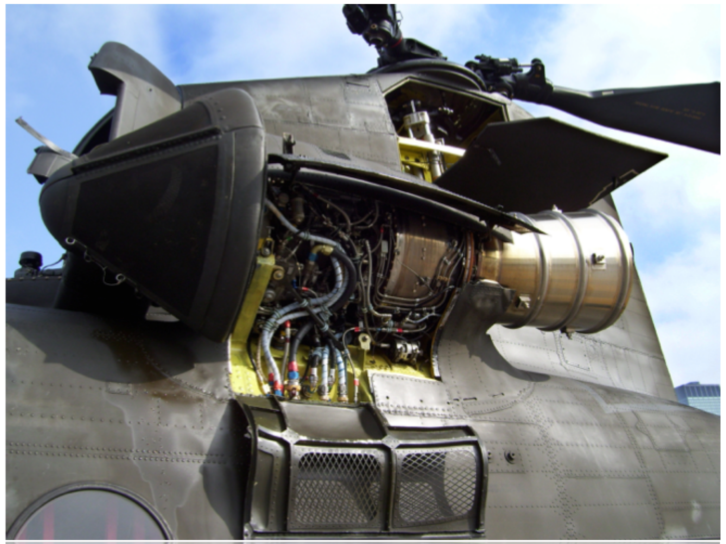
15×10^3

Aeroacoustics:

Aircraft Noise Simulation

Motivation:

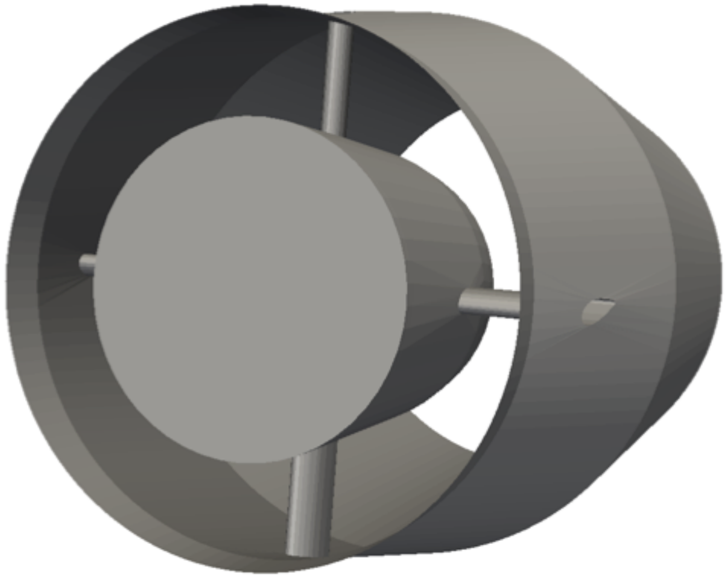
- **Flightpath 2050: reduce noise by 65% in comparison to the year 2000**
- **predict the emitted noise by numerical simulations**
- **use predictions to design low-noise and highly-efficient engines**



helicopter engine nozzle

Approach:

- **use FVM to simulate the turbulent flow (LES)**
- **simulate the aeroacoustics using a DG-solver**

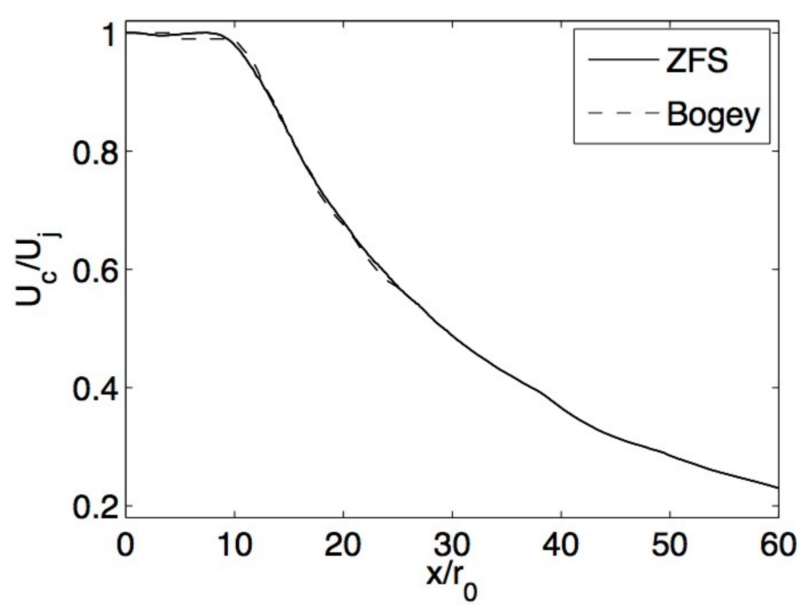


nozzle geometry, © TURBOMECA

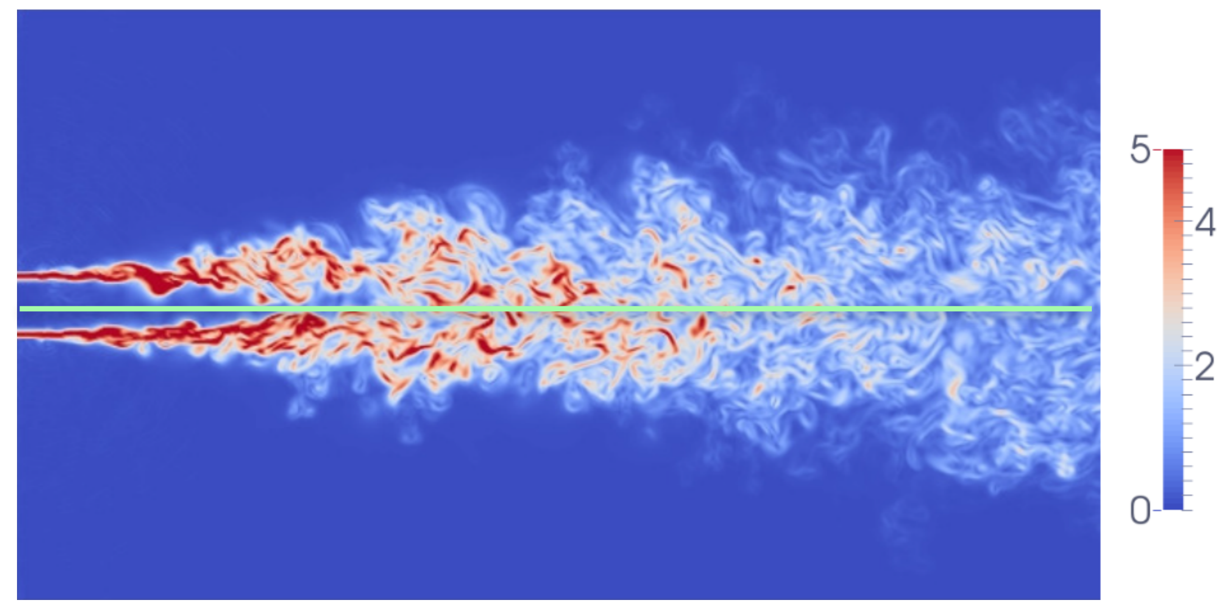
Aeroacoustics:

Aircraft Noise Simulation (COPA-GT project)

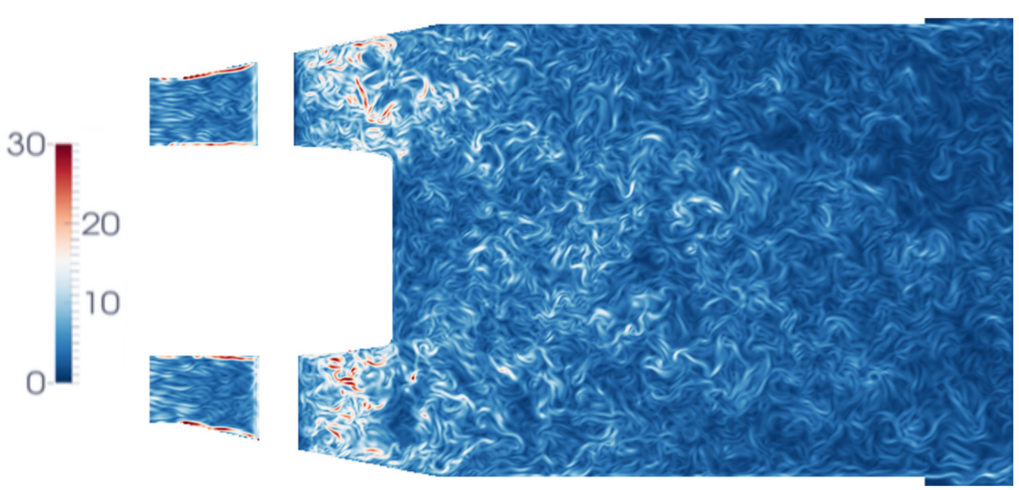
Cooperation with the Institute of Aerodynamics (AIA) at RWTH Aachen University



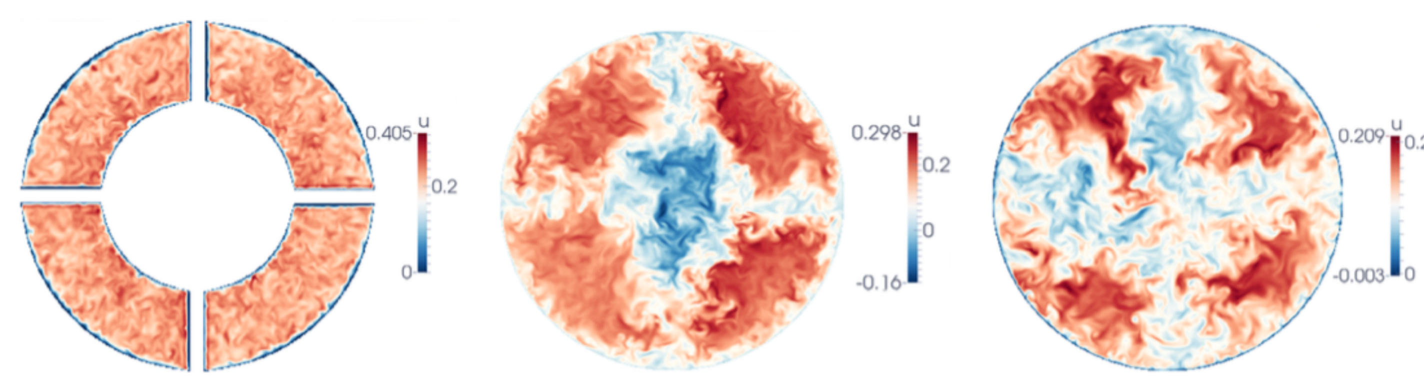
comparison of the centerline velocity



simulation of a turbulent jet, velocity gradient Re=400000, Ma=0.9



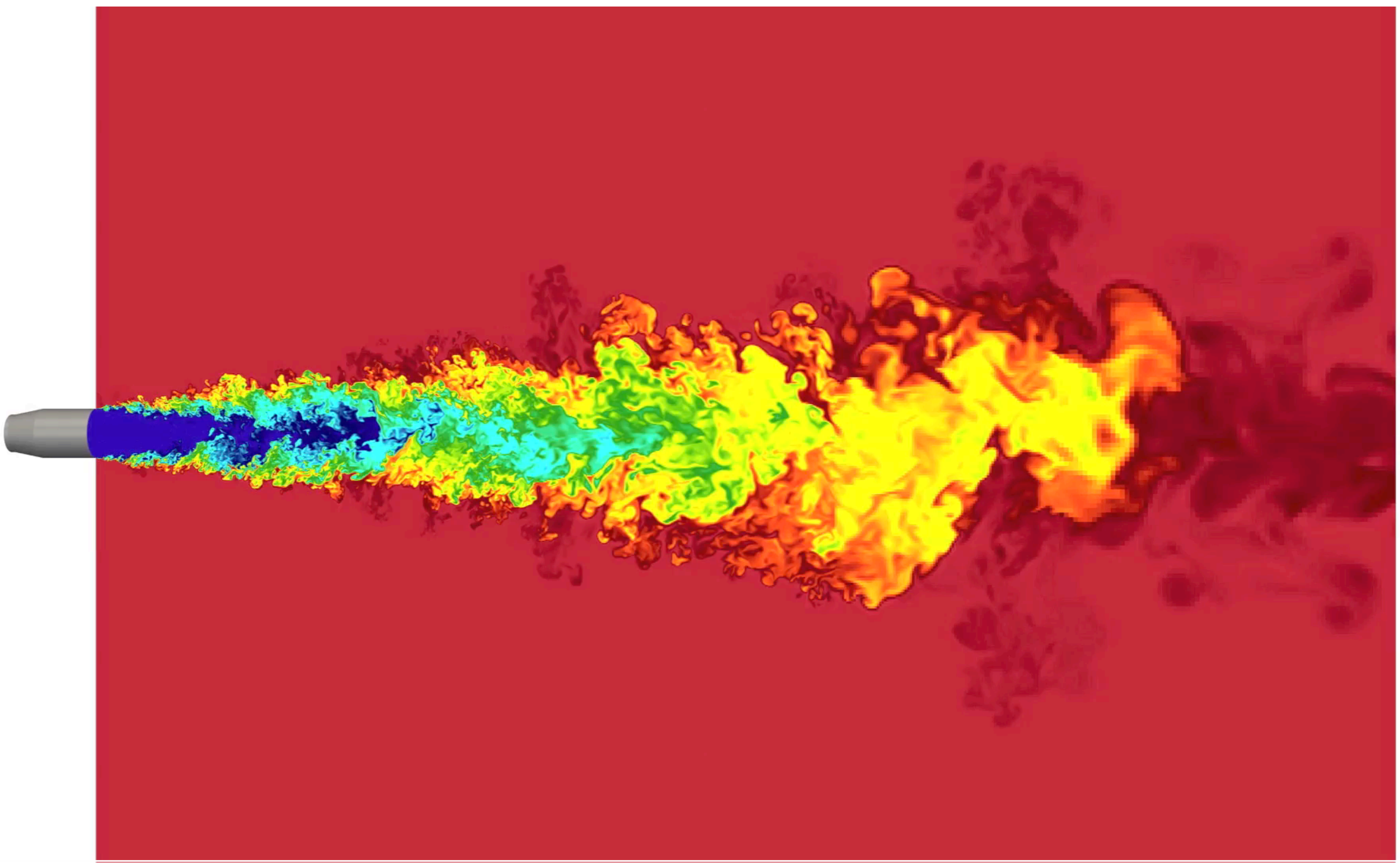
contours of the velocity gradient, Re=750000, Ma=0.341



instantaneous velocity distribution

Aeroacoustics:

Aircraft Noise Simulation (COPA-GT project)

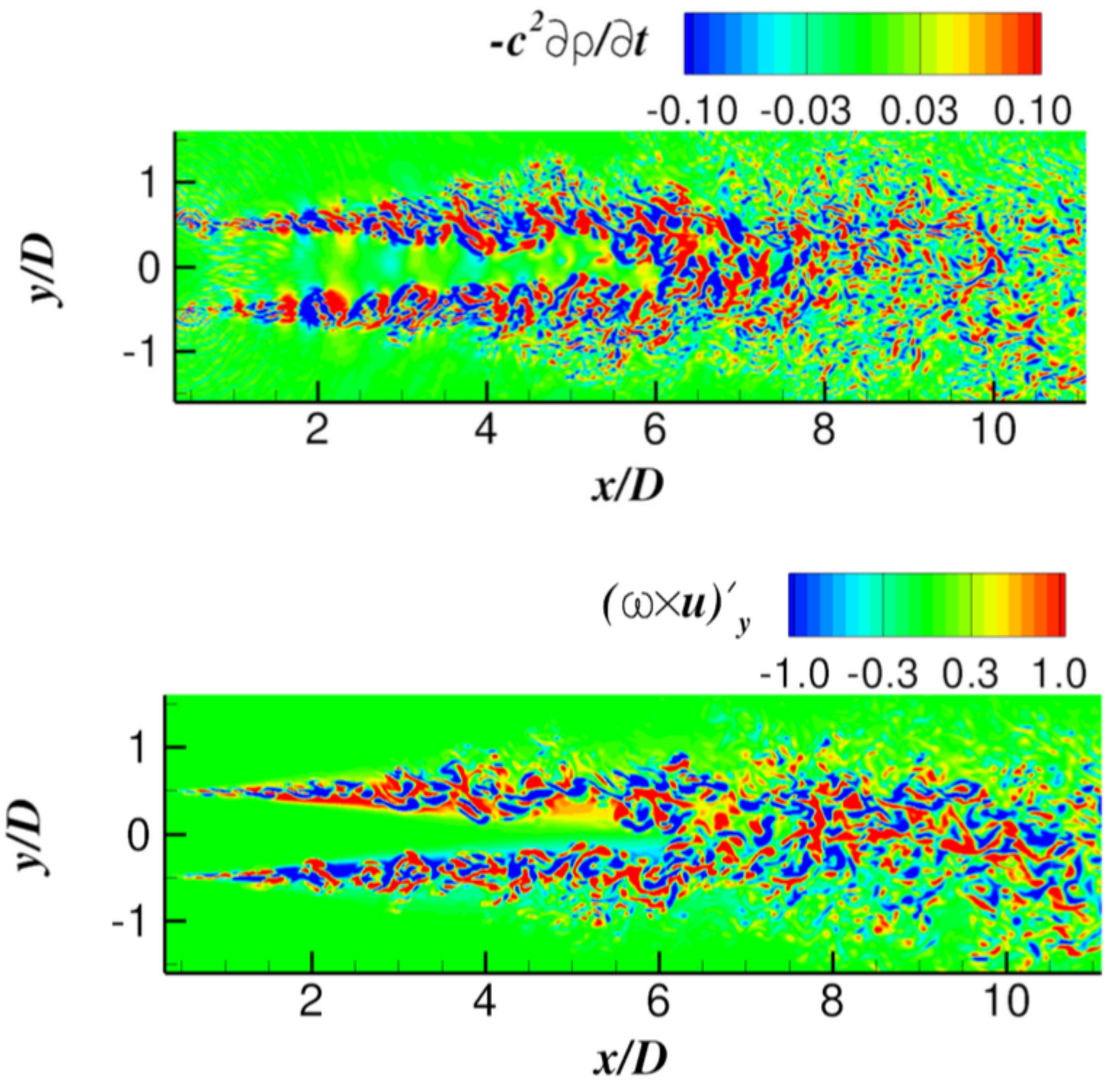


density distribution in a turbulent jet

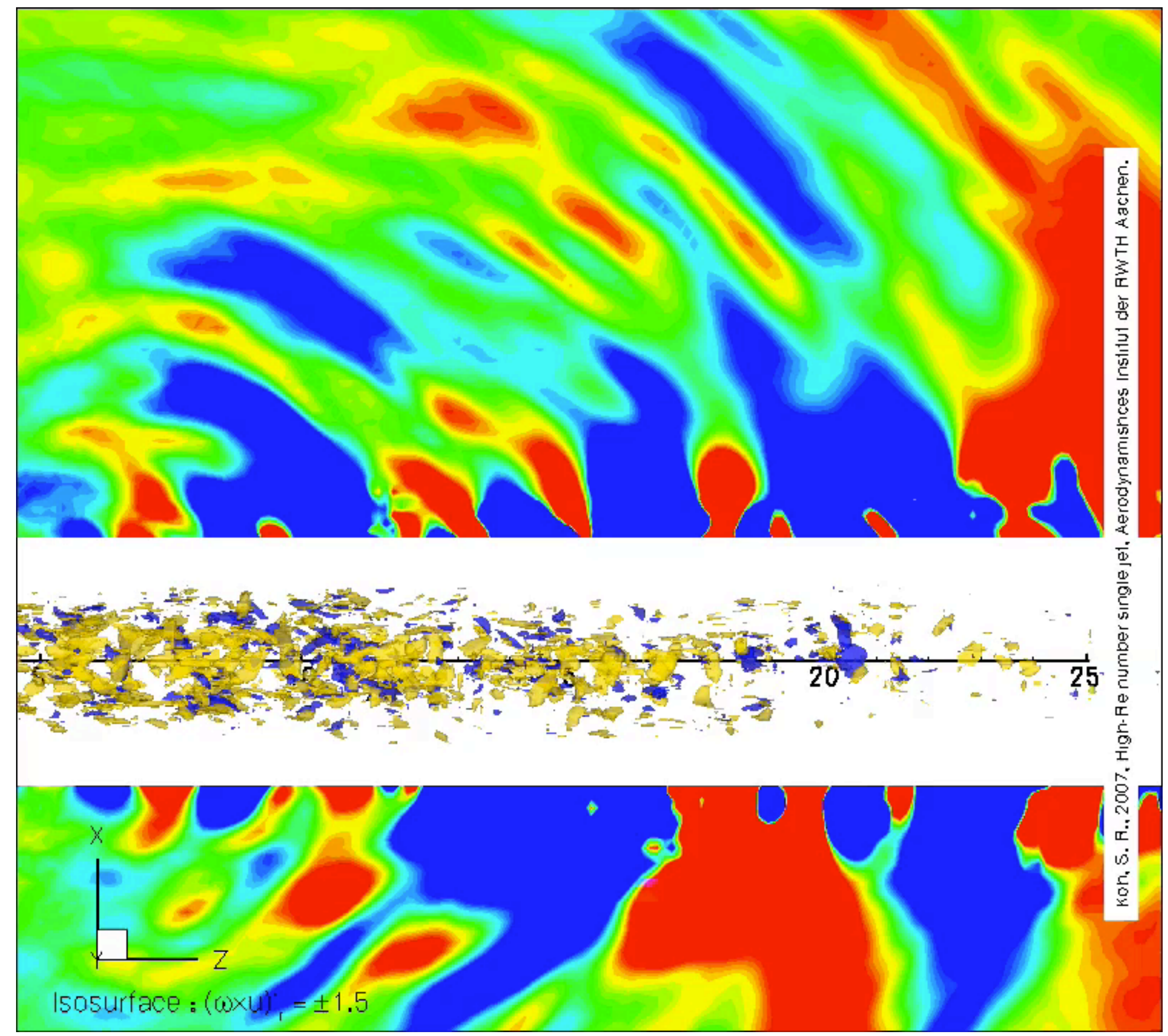
JÜLICH FORSCHUNGSZENTRUM

Aeroacoustics:

Aircraft Noise Simulation (COPA-GT project)



source terms for the Acoustic Perturbation Equations



aeroacoustic pressure fluctuations of a turbulent jet

Challenges for future research projects:

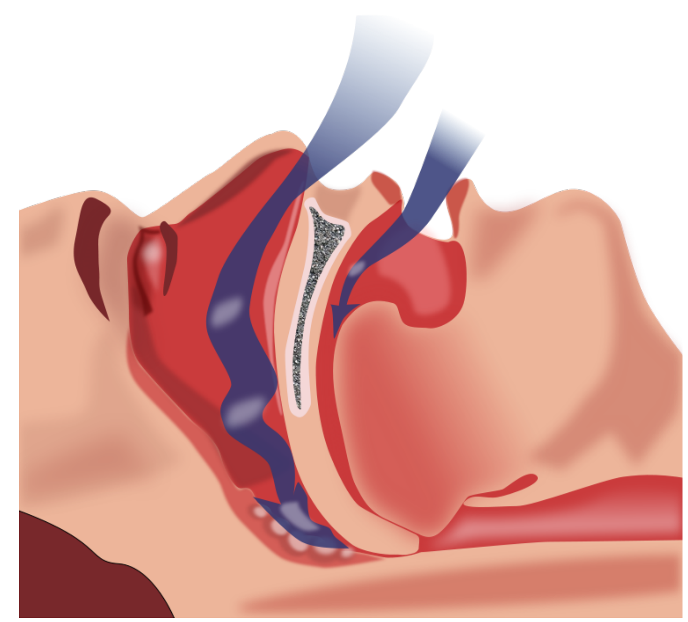
Future Research: Analysis of Respiratory Sleep Disorders

Motivation:

- **40% of women and 60% of men suffer from sleep disorders**
- **4% are affected by the Obstructive Sleep Apnea Syndrome (OSAS)**
- **common consequences are:**
  - cerebral and myocardial infarction
  - heart failure
  - asthma
  - hyperinsulinism, -tension, and -lipidemia

Approach:

- **use LBM to simulate the unsteady flow**
- **couple structure solver to LBM**



airway collapse in the OSAS, © Wikipedia

Challenges for future research projects:

Analyses of Respiratory Sleep Disorders

Project challenges:

- extraction of the involved tissue and air volume from CT-data
  - what are the flexible regions?
  - which algorithms are suited for an extraction?
- full DNS of the unsteady respiratory cycle including FSI
- efficient coupling of solvers
  - how to efficiently handle the data exchange?
- modelling of an anisotropic, inhomogeneous, and viscoelastic material
  - what tissue models should be used?
- dynamic parallel remeshing due to tissue movements
  - how to achieve optimal load-balancing?

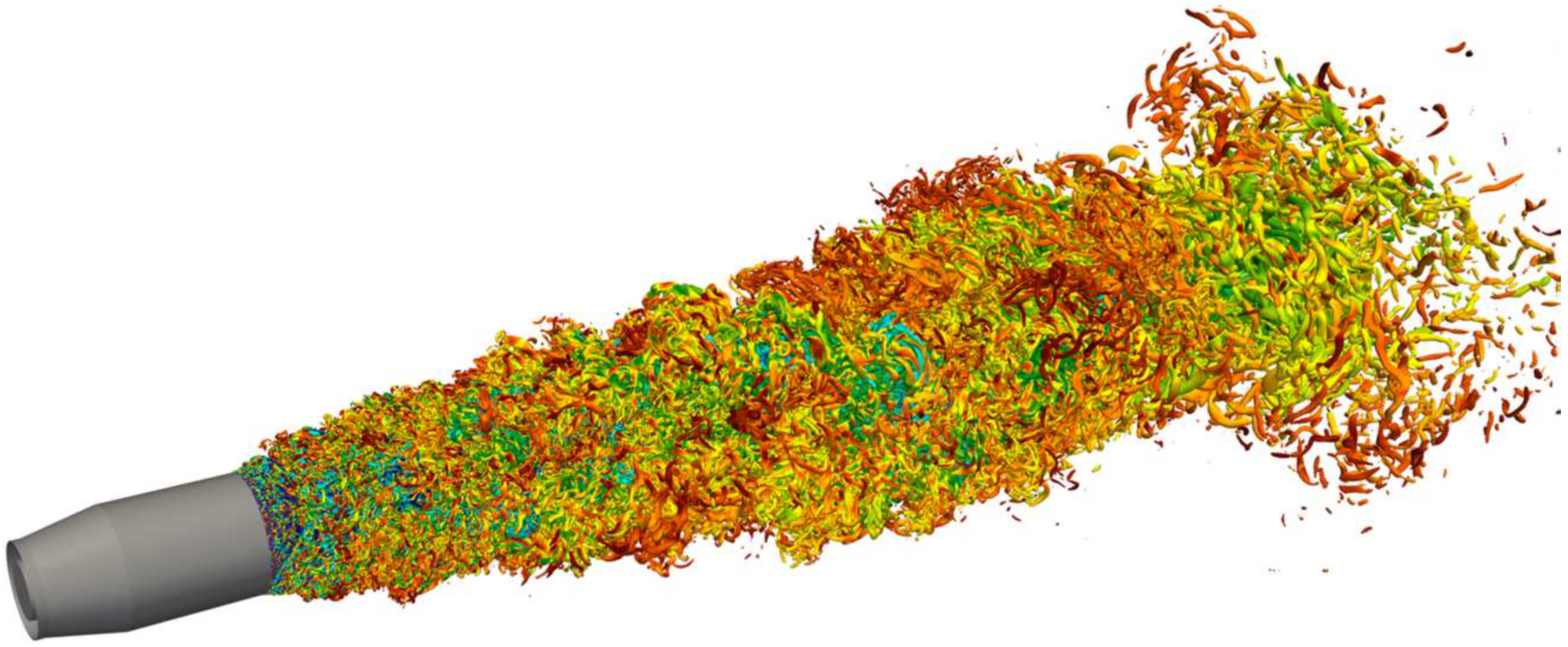
Challenges for future research projects:

in-situ Processing of Simulation Data

	Reynolds number	mesh points	mesh size	samples	sample size	$\sum$ sample size
LES	$0.75 \cdot 10^6$	$1.1 \cdot 10^9$	$130\ GB$	3000	$41\ GB$	$123\ TB$
DNS	$0.75 \cdot 10^6$	$\approx 1.66 \cdot 10^{13}$	$\approx 1.9\ PB$	3000	$\approx 616\ TB$	$\approx 1.85\ EB$

Challenges:

- **what is the important data in our simulations?**
- **how do we efficiently filter the important from the unimportant data?**



JÜLICH
FORSCHUNGSZENTRUM

Summary

Simulation Laboratory "Highly Scalable Fluids & Solids Engineering"

- **Research, Support & Education**

Biofluidmechanics

- **Flow in the Human Nasal Cavity (LBM)**
- **(Particle) Flow in the Human Lung (LBM, Lagrange)**

Aeroacoustics

- **Aircraft Noise Simulation - COPA-GT**

Future research

- **Analysis of Respiratory Sleep Disorders**
- ***in-situ* Processing of Simulation Data**